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YUCCA MOUNTAIN – SUPPLEMENTAL RESPONSE – REQUEST FOR ADDITIONAL INFORMATION (RAI) –VOLUME 2, CHAPTER 2.1.1.4, SET 3 (DEPARTMENT OF ENERGY'S SAFETY ANALYSIS REPORT SECTION 1.7) – Identification of Event Sequences

References: 1. Ltr, Jacobs to Williams, dtd 6/03/09, "Yucca Mountain - Request for Additional Information – Volume 2, Chapter 2.1.1.4, Set 2 and Set 3 (Department of Energy's Safety Analysis Report Section 1.7)"

2. Ltr, Williams to Jacobs dtd 7/07/09, "Yucca Mountain - Request For Additional Information (RAI) –Volume 2, Chapter 2.1.1.4, Set 3 (Department of Energy's Safety Analysis Report Section 1.7)" – Identification of Event Sequences

The purpose of this letter is to transmit the U.S. Department of Energy's (DOE) supplemental response to one (1) Request for Additional Information (RAI). For supplemental RAI Number 1, Questions #5 and #7 are provided as separate enclosures. The original response to that RAI was provided on July 7, 2009, by Reference 2.

Three DOE references, not previously submitted to the U.S. Nuclear Regulatory Commission (NRC), are provided on optical storage media (OSM) as Enclosure 3. Additionally, Enclosure 4, on OSM, contains electronic attachments associated with two of the references. The electronic attachments are data files provided in their native file format, consistent with Sections 2.2 and 2.17 of the NRC guidance on electronic submissions. They are required by NRC staff in their native format to evaluate DOE's responses. The electronic attachments are not intended to be placed on or accessed through ADAMS, and will be made available to the public upon request. DOE expects to submit the remaining supplemental responses on or before December 21, 2009.

There are no commitments made in the enclosed supplemental response. If you have any questions regarding this letter, please contact me at (202) 586-9620, or by email to jeff.williams@rw.doe.gov.

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OTM:SAB-0146

Enclosures (4):
1. Supplemental Response to RAI Volume 2, Chapter 2.1.1.4, Set 3, Number 1 Question #5
2. Supplemental Response to RAI Volume 2, Chapter 2.1.1.4, Set 3, Number 1 Question #7
3. Optical Storage Media – DVD containing three references
4. Optical Storage Media – DVD containing electronic reference attachments

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<u>EIE Document Components</u>:

[181812]_800-K0C-SSD0-00200-000-00B.pdf	83,829 kB
[183012]_000-00R-G000-00600-000-001.pdf	8,528 kB
[184919]_000-00R-G000-01000-000-000.pdf	115,638 kB

RAI Volume 2, Chapter 2.1.1.4, Third Set, Number 1, Supplemental Question 5:

Clarify the DOE's plan for ensuring sufficient air flow through the ventilation exhaust system if one or more openings used for exhaust air flow (e.g., on exhaust main or shaft) were to be blocked due to rock collapse.

1. RESPONSE

The inherent stability of the excavated openings in the volcanic tuff as well as the results of ground support analyses, which are described below, demonstrate that the repository openings will maintain their integrity during the preclosure period, during normal operations, and for the design basis ground motions. The calculations also demonstrate that, for design basis events for which rockfall may occur in openings with large roof spans, which are the most vulnerable opening locations, the estimated volume of rockfall is not sufficient to completely block a drift. Complete blockage of drifts is not predicted based upon the properties and stability of the rock. This response also describes the excess airflow capacity and the system flexibility offered by the repository design that allows operational modifications to redistribute airflows during mitigation of off-normal events.

As stated in SAR Section 1.3.2.4.4.3, the ground support for inaccessible nonemplacement area openings is designed to function without planned maintenance during the preclosure period (100 years). Ground supports for nonemplacement openings are classified as not important to safety and not important to waste isolation. The design information from *Ground Control for Non-Emplacement Drifts for LA* (BSC 2007a) and the *Shaft Liner Design* (BSC 2008a) calculations demonstrate the stability of inaccessible portions of the exhaust side openings. In addition, as discussed further below, aspects of the subsurface layout design and ventilation system operating capabilities provide for response to off-normal events.

Even though a rockfall that would result in a blockage of exhaust airflow is an unlikely event, the subsurface repository configuration ensures sufficient airflow is available to maintain design basis ventilation flow rates. The SAR describes the ventilation system capability for this condition for a fully developed repository (with all shafts and ventilation equipment in place) through the use of the airflow network calculations and other analyses.

From a ground support standpoint, the drift intersection areas with large roof spans (SAR Figures 1.3.3-23 and 1.3.3-27) are the most susceptible to rockfall. On the exhaust side of the repository ventilation system, these locations include the emplacement drift–exhaust main intersections and the shaft access drift–shaft intersections. As such, the design calculations (BSC 2007a; BSC 2008a) analyzed these intersections, and the ground support components are designed to provide sufficiently robust support in these intersections.

Minor rockfalls due to failed ground support in exhaust mains, exhaust shaft access drifts, or intersections formed by emplacement drifts and exhaust mains may not necessarily require maintenance actions. The following list of conditions would be evaluated to determine if actions other than monitoring are required (BSC 2008b):

- The rubble accumulation on the floor, to ensure that it does not become a detrimental blockage to ventilation
- The damaged area, to ensure that it does not get progressively worse and stabilizes due to natural arching effects
- The rubble, to ensure that it does not become an obstacle for an inspection vehicle

1.1 GROUND SUPPORT DESIGN APPROACH

Ground support calculations analyze the performance of excavations without ground support, and then the excavations are evaluated with the ground support added. Applicable thermal and seismic loads are considered in the design in addition to the *in situ* loading conditions. Both empirical and analytical methods are employed in the ground support design calculations. The empirical methods are primarily used for assessing the needs for ground support of nonemplacement drifts and determining the appropriate type of ground support for such locations. The analytical methods use two-dimensional and three-dimensional finite difference computer codes to model the three-dimensional rock structures, ground support performance, and coupled mechanical and thermal-mechanical interactions. Based on empirical estimates, design constraints, and computer modeling results, the final ground support system is developed.

Nonlithophysal units are generally hard, strong, fractured rocks with matrix porosities of 10% or less. In comparison, the lithophysal units have fewer fractures of significant continuous length, but have a relatively uniformly distributed porosity in the form of lithophysal cavities. Both emplacement drifts and nonemplacement openings are located within the same boundary for the underground repository. Approximately 85% of the repository emplacement drifts are located within the lithophysal rock units (Tptpll and Tptpul units), with the remaining 15% of the emplacement drifts located within the nonlithophysal units (Tptpmn and Tptpln units). In the lithophysal rock, 95% of the emplacement area lies in the Tptpll unit whereas in the nonlithophysal rock, 83% of the emplacement area lies in the Tptpmn unit. The nonemplacement openings adjacent to or within the emplacement area boundaries are, therefore, located primarily in the Tptpll and Tptpmn units.

1.2 STABILITY OF NONEMPLACEMENT DRIFTS

Ground Control for Non-Emplacement Drifts for LA (BSC 2007a) evaluated the stability of access mains, ramps, exhaust mains and turnouts, and their intersections. The *Prediction of Rockfalls in Nonemplacement Drifts Due to Preclosure Seismic Ground Motions* document (BSC 2007b) evaluated the size, quantity, and distribution of the potential rockfalls in the nonemplacement drifts, specifically in the area of access mains and turnouts, due to seismic ground motions.

Consistent with project ground support design methodology, *Ground Control for Non-Emplacement Drifts for LA* (BSC 2007a) analyzed the stability of unsupported and supported nonemplacement drifts based on a 2,000-year return period seismic event, that is, an event with an annual probability of exceedance of 5×10^{-4}. The evaluations considered excavation effects, thermal effects due to heat output from waste packages, and seismic effects. Stress-controlled modes of failure were examined for representative rock mass Categories 1 and 5, with the focus on the Category 1 rock, because it is weaker than other categories of rock mass. The analysis of the ground support in the nonemplacement drifts was carried out mainly for the Category 1 lithophysal rock mass, which is the poorest condition of rock mass quality at the repository level. No credit was given for the initial or temporary ground support in modeling the final ground support design.

Stability of Unsupported Nonemplacement Drifts—The unsupported nonemplacement openings show overall stability even for the Category 1 lithophysal rock (i.e., the lowest quality-rated rock mass category) due to the self-supporting capacity of the rock mass. The roof in the intersections is shown to be stable, even at locations of the largest spans.

Stability evaluations specific to the exhaust mains indicated that seismically-induced rock deformation is not significant. Similar stability evaluations conducted for the emplacement drift–exhaust main intersections determined that there is no indication of permanent stress redistribution or distressing of portions of rock mass indicating grounds prone to rockfall (BSC 2007a, Section 6.5.3.3.2).

Stability of Supported Nonemplacement Drifts—SAR Figure 1.3.3-25 illustrates the ground support configuration of a typical exhaust main excavation, and SAR Figure 1.3.3-24(b) illustrates the ground support configuration for a typical emplacement drift–exhaust main intersection. The ground support for intersections with large roof spans is enhanced with the use of an increased rock bolt length (5 m instead of 3 m) and installation of 0.10-m (4-in.) thick steel fiber-reinforced shotcrete. It is also supplemented with lattice girders, as necessary, depending on rock mass quality and the length of the roof span.

For supported nonemplacement openings, the computer model results do not indicate formation of a failure mechanism or the accumulation of residual displacement, which results from plastic deformation of the rock mass during shaking. However, the results do not imply that rockfall of any kind will not occur during an earthquake with a 2,000-year return period. The modeling is formulated based on continuum mechanics. Consequently, it was beyond the capability of the model used to simulate the formation of new fractures or reopening of existing fractures, which could form loosened blocks resulting in rockfall. The analysis implies that, if there is no ground support, the rockfall will be limited and confined to the drift boundary.

Seismic loads have an insignificant effect on the rock bolts. The shotcrete would be damaged during an earthquake with a 2,000-year return period, but that damage (mostly tensile cracks) would be localized. The maximum rock bolt load in the exhaust main part of the excavation is around 150 kilo Newton (kN), with the exception of a few bolts affected by the local conditions. The maximum force on the bolts increases to approximately 200 kN in the regions above the intersections of the exhaust mains with the emplacement drifts. The maximum increase in rock bolt forces due to seismic loading compared to the static condition is approximately 3 kN in the regions above the intersections, with the resulting rock bolt loads being less than their yield strength of 264 kN.

The force in the exhaust main rock bolts increases during the preclosure period due to repository thermal loads. However, even using a conservative analysis, the predicted maximum force in the rock bolts is about 198 kN, which is less than their yield strength. In the simulations of intersections, the rock blocks were modeled to behave effectively as a continuum; therefore, the local stability of blocks created by joints around the excavation was not considered. However, such blocks will be of limited size and number and will be effectively supported by the ground support (BSC 2007a, Section 7.4).

Design Sensitivity—A sensitivity study within *Ground Control for Non-Emplacement Drifts for LA* (BSC 2007a, Section 6.6) analyzed unsupported exhaust mains in Category 1 lithophysal and nonlithophysal rock mass subjected to the seismic events with a mean annual probability of exceedance of 1×10^{-4}, in addition to the analysis for the design basis earthquake (mean annual probability of exceedance of 5×10^{-4}). The drift closures calculated for the seismic events with an annual probability of exceedance of 1×10^{-4} are only slightly higher for the exhaust mains, as compared to closure results when the drifts are subjected to the seismic events with an annual probability of exceedance of 5×10^{-4}, but still not significant. The maximum closures of the drift openings due to seismic loadings are predicted to vary from less than 9 mm for the Category 1 lithophysal rock to less than 5 mm for the Category 1 nonlithophysal rock. The drift stability conditions predicted under seismic events with an annual probability of exceedance of 5×10^{-4} generally prevail for drifts under seismic events with an annual probability of exceedance of 1×10^{-4} (BSC 2008a, Section 6.6).

Prediction of Rockfalls in Nonemplacement Drifts—An earlier report, *Prediction of Rockfalls in Nonemplacement Drifts Due to Preclosure Seismic Ground Motions* (BSC 2007b), evaluated the size, quantity, and distribution of the potential rockfalls in the nonemplacement drifts, specifically in the area of access mains and turnouts for unsupported drifts. This document examined seismic events with annual probabilities of exceedance of 1×10^{-4} and 1×10^{-5} (BSC 2007b, Section 6.4.3) for the access main–turnout intersections and was developed to evaluate the impact of rockfalls on the transport and emplacement vehicle. The *Ground Control for Non-Emplacement Drifts for LA* (BSC 2007a) calculation used ground motions with an annual probability of exceedance of 1×10^{-4} in the sensitivity evaluations of unsupported and supported openings. For comparison, the *Prediction of Rockfalls in Nonemplacement Drifts Due to Preclosure Seismic Ground Motions* calculation also used ground motions with an annual probability of exceedance of 1×10^{-4}, resulting in an estimated total rockfall volume of 188.22 m^3 in an unsupported emplacement drift–turnout intersection (BSC 2007b, Table 6-8). This indicates that, for an unsupported emplacement drift–turnout intersection with an exposed surface area, at the intersection of the access main and the turnout, of approximately 310 m^2 (BSC 2007b, Section 6.5.3), the postulated rockfall would not result in complete blockage of the drift.

1.3 STABILITY OF EXHAUST SHAFTS

The *Shaft Liner Design* calculation evaluated the shaft stability, the shaft ground control and reinforcement, and the shaft liner required for the anticipated construction, *in situ*, thermal, and seismic loads during the preclosure period (BSC 2008a[1]).

Design of shafts considers seismic loads up to a design basis ground motion 2 (annual exceedance probability of 5×10^{-4}) and sensitivity analyses for ground motions from a seismic event with an annual probability of exceedance of 1×10^{-4} (SAR Section 1.3.3.3). SAR Figures 1.3.3-16 and 1.3.3-27 illustrate the ground support details for the shaft–shaft access drift intersections.

The shaft liner calculation's methodology first evaluates the performance of a shaft excavation without ground support, and then the support liner is added. The unsupported shaft case is used as a benchmark of shaft performance to which the performance of the shaft with the liner installed is compared. Similar to the exhaust main intersections, the large roof spans at the shaft access drift–shaft intersections use 5-m rock bolts and wire mesh, enhanced with a 0.10-m (4-in.) thick layer of steel fiber-reinforced shotcrete (SAR Figure 1.3.3-27).

Stability of Unsupported (Unlined) Shafts—For the unsupported shaft, results of modeling indicate that, for the ground conditions considered, shaft excavations are expected to be stable along their entire depths. The results of modeling analysis on an unlined shaft due to *in-situ* stresses indicate that shaft excavations are expected to be stable along their entire depths under all ground conditions considered (BSC 2008a, Section 6.5.1). The expected shaft closure is relatively small and there are no indications of stability problems during shaft-sinking activities under analyzed conditions. Static and dynamic analyses of the unlined shaft indicate that shaft–shaft station intersections remain stable. Although a small plastic zone develops at the tunnel surface, the overall magnitudes of deformations are relatively small (BSC 2008a, Section 6.5.1.4).

Due to the spans encountered where shaft access drifts connect to the shafts, the shaft liner analysis evaluated typical types of shaft–drift intersections. Two types of intersections, the "T-type" intersection and the "L-type" intersection (SAR Figure 1.3.3-28), were modeled and the results indicate that, for both intersections, all strata points move in unison, showing no evidence of irreversible deformation accumulation in the intersection region. This suggests that the intersections are stable.

Stability of Supported (Lined) Shafts—Thermal loads in combination with seismic loads may cause localized fracturing in the shaft liner where the maximum tensile stresses (elastic) are larger than the tensile strength of concrete. The resulting stresses may cause tensile cracks to develop. Such lateral cracks are common in typical mine shaft structures, generally do not pose any safety or operational difficulties, and are not expected to require maintenance (BSC 2008a, Section 6.5.2.2.2).

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[1] The reference BSC 2008a was submitted as part of the response to RAI 2.2.1.1.4-3-001 (RTN 00409-04).

The shaft liner concrete is considered to behave as a linearly elastic material, and the working stress method was used to assess the performance of the shaft liner under different loading conditions. Deformations will cause stress relief and, as a consequence, actual stresses generated will most likely be lower than those calculated from the linear elastic analysis. A conservative approach was followed in selecting design inputs and analysis methodology, which results in the calculated stresses being considered as bounding values and the overall shaft performance under thermal and seismic loads being considered acceptable (BSC 2008a, Section 6.5.3).

In general, the thermal loading cases indicate that the liner stresses do not exceed the allowable stresses (additional information provided in response to RAI 2.2.1.1.4-3-001). Shafts will be inspected during the preclosure period, however, it is expected that no routine or planned maintenance will be required.

1.4 SUBSURFACE LAYOUT CONFIGURATION

The subsurface layout configuration calculations (BSC 2003; BSC 2007c) have considered response to off-normal events during the design development. SAR Section 1.3.5 describes this capability for a fully developed repository (with all shafts and ventilation equipment in place), as analyzed with the use of the airflow network calculations and other analyses.

The underground layout configuration is a modular design that provides flexibility to meet thermal goals (SAR Section 1.3.1.2.5), and provides the capability for alternate ventilation airways using the existing openings, should one of the airways fail. Exhaust shafts have been positioned at the ends of each panel, except in Panel 1, to provide for diversion of the airflow if required (Figure 1). The subsurface layout ventilation components, consisting of three shafts and three ramps on the intake side and six shafts on the exhaust side, provide a minimum of 20% extra capacity overall (BSC 2003, Section 8.6).

Fully Emplaced Repository—Except for Panel 1, the design of the subsurface layout provides for multiple exhaust shafts in each emplacement panel, which are typically located at the northern and southern ends of each panel. In addition, the exhaust airway drifts are interconnected where possible and the shaft access drifts are designed to accommodate airflows from different sources (Figure 1). For example, the Panel 3 and Panel 4 Exhaust Main is a continuous excavation with Exhaust Shaft #3N configured to exhaust air from Panels 3E, 3W, and 4. Exhaust Shaft #3S provides a second exhaust airway at the south end of Panel 3E. Exhaust Shaft #4 is configured to exhaust air from Panels 3W and 4, and the Enhanced Characterization of the Repository Block (ECRB) exhaust shaft can exhaust air from Panels 1, 2, 3W, and 4. The Panel 2, 3W, and 4 exhaust airflow paths are connected via the ECRB cross-drift and internal raises.

Initial Emplacement for Panel 1—The initial emplacement will occur in Panel 1, in the central part of the overall subsurface layout. Exhaust Shaft #1 is the only exhaust source for initial emplacement in Panel 1, and in the event that Exhaust Shaft #1 is unavailable during the initial development and emplacement phase, the ECRB exhaust shaft could be reconfigured as the alternate exhaust airflow route. The ECRB exhaust shaft is constructed prior to initial waste emplacement to provide intake air to the second phase of construction via an internal raise (SAR

Figure 1.3.5-15). Because the failure of Exhaust Shaft #1 would be an off-normal event, and no readily available second exhaust airflow route is available, the ECRB exhaust shaft and selected isolation barriers in the Panel 1 area would need to be reconfigured (addition of bulkheads) to redirect exhaust airflows. Such changes can be made in a reasonable period of a few days without detrimental thermal impacts.

This single exhaust shaft condition exists only during the initial emplacement period. During other phased repository development beyond Panel 1, the capability exists to provide alternate ventilation airways using the existing openings, should one of the airways fail.

1.5 SUBSURFACE VENTILATION SYSTEM

The subsurface ventilation system is neither important to safety nor important to waste isolation because the system does not prevent or mitigate an event sequence during the preclosure period and does not contribute to a significant barrier function in the postclosure period (SAR 1.3.5.3). The subsurface repository configuration contains multiple fan installations, numerous intake and exhaust airway paths, and interconnected access and exhaust mains, as illustrated in Figure 1. Because the access drifts are interconnected in the subsurface, the fan design contains allowance for increased capacity in both volume and corresponding motor power requirements. The cross-sectional area of the exhaust shafts allows for an airflow volume increase without exceeding installed power and without exceeding the air velocity guidelines (BSC 2008c, Table 21) or constraints described in SAR Section 1.3.2.

The design for the exhaust shaft fans includes a 15% airflow volume contingency in both the fan capacity and the fan motor power (BSC 2008b, Section 6.2.1.2). If an exhaust shaft were unavailable, the nearby fans could have their airflow discharge capacities increased by adjusting the motor rotational speed, and/or by adjusting pitch of the fan blades. The emplacement drift airflows in the affected area could be reduced to some degree (refer to SAR Section 1.3.5.3.2.2) without detrimental effects until the system can be returned to its normal configuration (BSC 2008d, Sections 6.4.3 and 6.4.8).

1.6 SUMMARY

Ground Control for Non-Emplacement Drifts for LA (BSC 2007a) evaluated the stability of supported nonemplacement openings, and the analyses do not indicate formation of a failure mechanism or the accumulation of residual displacement of the rock mass during design basis seismic shaking. For beyond design basis ground motions with an annual probability of exceedance of 1×10^{-4}, the total rockfall volume of 188.22 m^3 in an unsupported emplacement drift–turnout intersection (the most vulnerable location because of the larger roof span) indicates that the postulated rockfall would not result in a complete drift blockage and corresponding airflow blockage.

The *Shaft Liner Design* (BSC 2008a) calculation evaluated the shaft stability and the shaft ground support, and determined the ground support system is designed to be functional with no planned maintenance during the operational life. The evaluations determined that large span shaft access drift–shaft intersections were stable, even with the additional thermal load from the exhaust airflow.

The subsurface layout configuration provides multiple exhaust shafts in each emplacement panel, which are typically located at the northern and southern ends of each panel. The quantity of three shafts and three ramps on the intake side, and six shafts on the exhaust side provide a minimum of 20% extra ventilation overall capacity. Access drifts (airways) are interconnected in the subsurface, and fan designs contain allowances for increased capacity in both volume and corresponding motor power requirements.

For nonaccessible nonemplacement openings, any unplanned maintenance requirements that may be necessary because of installation flaws, material defects, off-normal operational conditions, or unfavorable inspection results will be evaluated with full consideration of the information gathered during the inspection and monitoring activities. These maintenance activities, if necessary, can be performed without affecting repository operations as discussed in SAR Section 1.3.5.

2. COMMITMENTS TO NRC

None.

3. DESCRIPTION OF PROPOSED LA CHANGE

None.

4. REFERENCES

BSC (Bechtel SAIC Company) 2003. *Underground Layout Configuration*. 800-P0C-MGR0-00100-000-00E. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20031002.0007.

BSC 2007a. *Ground Control for Non-Emplacement Drifts for LA*. 800-K0C-SSD0-00400-000-00A. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20071001.0042.

BSC 2007b. *Prediction of Rockfalls in Nonemplacement Drifts Due to Preclosure Seismic Ground Motions*. 800-K0C-SSD0-00200-000-00B. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20070625.0043.

BSC 2007c. *Underground Layout Configuration for LA*. 800-KMC-SS00-00200-000-00B. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20070727.0004.

BSC 2008a. *Shaft Liner Design*. 860-K0C-SSD0-00100-000-00B. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20080215.0003.

BSC 2008b. *Ground Support Maintenance Plan*. 800-30R-SSD0-00100-000-00C. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20080215.0001.

BSC 2008c. *Subsurface Ventilation Network Model for LA*. 800-KVC-VUE0-00200-000-00B. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20080115.0013.

BSC 2008d. *Subsurface Construction and Emplacement Ventilation*. 800-KVC-VU00-00900-000-00C. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20080124.0010.

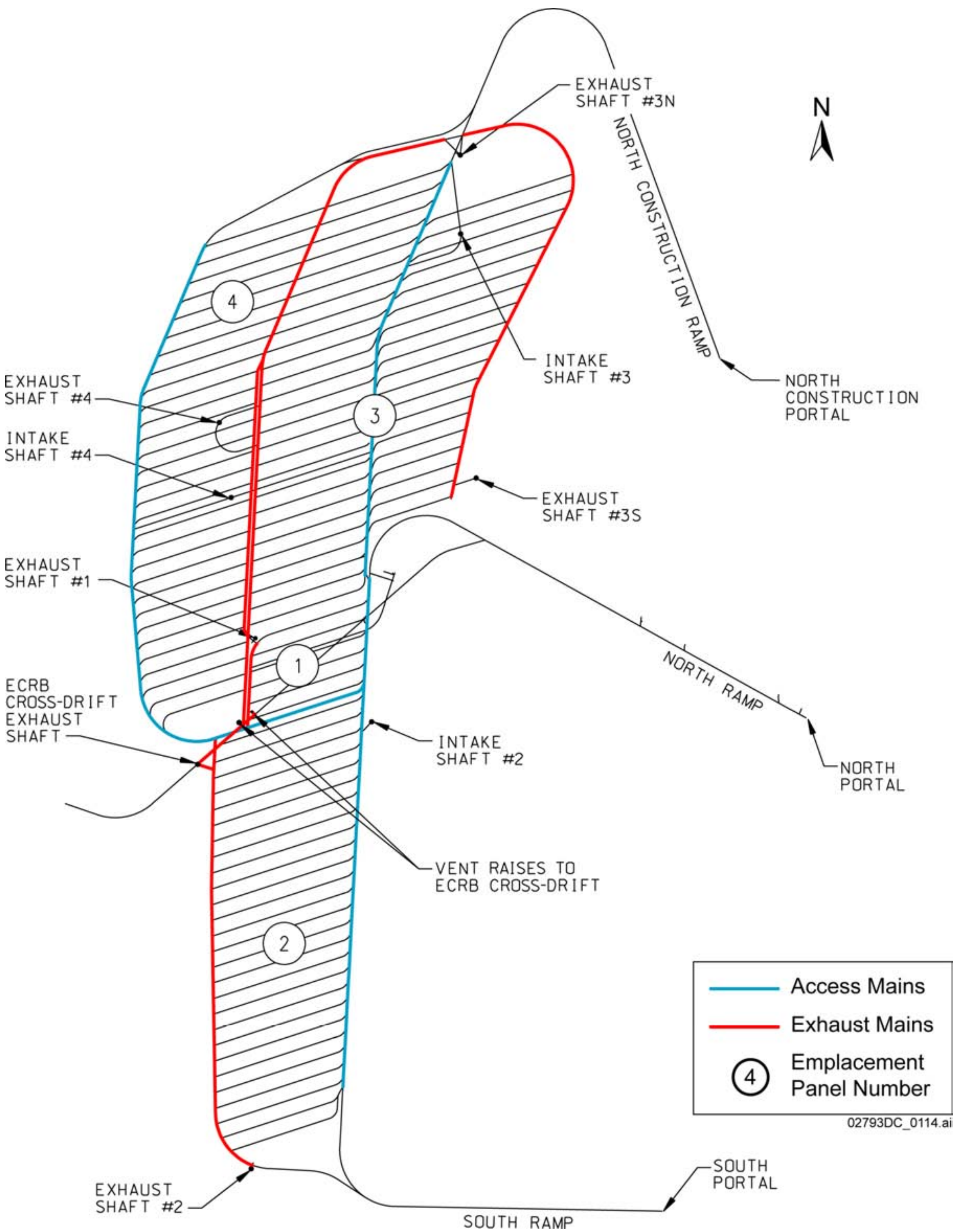

Figure 1. Subsurface Repository Intake and Access Mains

RAI Volume 2, Chapter 2.1.1.4, Third Set, Number 1, Supplemental Question 7:

To clarify DOE’s plan to ensure sufficient ventilation of waste packages to meet repository thermal limits, provide documentation that shows the calculations and methodology to obtain local and overall average thermal line loads, in enough detail to enable a review of the estimated limiting waste stream average line load in SAR Figure 1.3.1-6.

1. RESPONSE

The analyses and calculations in support of the repository thermal management, including development of the estimated limiting waste stream, are cited in SAR Section 1.3.1.2.5. A summary of thermal management is provided in that SAR Section for preclosure considerations, and in SAR Section 2.3.5.4.3 for postclosure thermal performance considerations.

The estimated limiting waste stream was developed from cases run with the total system model, as described in *Engineering Study: Total System Model Analysis for Repository Postclosure Thermal Envelope Study, Phase 1* (BSC 2007a). The total system model was developed originally for simulating preclosure repository operations. For this application, the total system model was used to simulate the selection and packaging of commercial spent nuclear fuel (SNF) at the power stations, transportation to Yucca Mountain, and handling at the repository surface facilities (BSC 2007a; BSC 2007b). The constraining criteria used in the simulation included those related to: the available waste inventory over time; shipment schedule for high-level radioactive waste and defense SNF; capabilities at the commercial sites; availability of transportation, aging, and disposal (TAD) canisters; availability of transportation casks; and mode of shipping. The estimated limiting waste stream is the result of a particular case, which used the following criteria to represent selection of commercial SNF for packaging and shipment to the repository:

- Youngest-fuel-first
- Minimum age of 5 years out-of-reactor
- Maximum canister thermal output of 22 kW for shipping (i.e., the YFF5-22 kW case).

As stated in SAR Section 1.3.1.2.5, the estimated limiting waste stream simulates waste deliveries in conformance with the commercial utility contracts, but is developed only as a representative case, since the actual waste receipt is yet to be determined.

The estimated limiting waste stream description from the total system model includes thermal decay histories for every commercial SNF TAD canister shipped to the repository (SNL 2008, Appendix B). The total system model also modeled the loading of TAD canisters in the Wet Handling Facility from uncanistered commercial SNF assemblies shipped to the repository. These model features yielded a one-to-one correspondence between TAD canisters and waste packages. In addition, a schedule for receiving high-level radioactive waste and defense SNF at the repository was adopted (BSC 2007a, Sections 2 and 4), and representative thermal decay histories for codisposal packages were developed. Thus, the delivery schedule and discrete thermal decay histories for all waste packages in the repository were made available for analysis of thermal loading. The total numbers of commercial SNF and codisposal waste packages are consistent with the 70,000 MTHM equivalent of the total waste inventory allocated to the repository (SAR Section 1.3.1.2.5).

The average thermal line load for the estimated limiting waste stream is calculated by assigning the appropriate lengths to each waste package type, summing the thermal output across all waste packages, and dividing by the total length (SNL 2008, Section 6.1.2). This is the estimated limiting waste stream average line load shown in SAR Figure 1.3.1-6.

To evaluate the range of local average thermal line loads in the repository, emplacement of the estimated limiting waste stream in the subsurface was simulated by using a postprocessing algorithm for the total system model output. For this purpose, an index of thermal energy density was developed specific to each commercial SNF and codisposal waste package, and the waste packages were emplaced so that a running average of this index was less than a prescribed limit (SNL 2008, Section 6.1.3). The thermal energy density for a single waste package is that thermal energy content that results in the peak midpillar temperature if the entire repository was loaded with waste packages with identical thermal decay histories, and is therefore described in terms of the midpillar temperature. The running average is then an estimate of the local peak midpillar temperature, calculated with the thermal energy densities for all the waste package types represented in a given drift segment. As stated in SAR Section 1.3.1.2.5, approximately half of the individual waste packages in the estimated limiting waste stream have an index of thermal energy density that exceeds the limit of 96°C. Therefore, those waste packages must be emplaced with, and proximal to, cooler packages so that the estimated local peak midpillar temperature is 96°C or cooler based on a running average over a seven-waste-package segment.

The postprocessing algorithm for the total system model kept track of the commercial SNF delivered to the repository and placed into surface storage for either fuel staging or aging, and then, at each loading opportunity, selected the waste package giving a running average value closest to the 96°C limit. Two other constraints were also imposed on commercial SNF waste package segments to control preclosure temperatures in the event of temporary loss of forced ventilation, as follows (SAR Section 1.3.1.2.5):

- The running average instantaneous thermal load at emplacement was limited to 2.0 kW/m; and

- The maximum output of any waste package was limited to 18 kW.

Waste package segments containing naval SNF are subject to different operational emplacement constraints including a lower limit for the thermal line load (1.45 kW/m), maximum thermal power of the naval waste package (11.8 kW/m), and naval waste packages cannot be emplaced in a waste package segment that contains a waste package with thermal power in excess of 11.8 kW as described in SAR Section 1.3.1.2.5.

The emplacement drifts were loaded with waste packages, one at time, yielding a sequence of more than 10,000 waste packages that was examined to find the hottest seven package segments (SNL 2008, Section 6.1.4). The maximum local average thermal line load of 2.0 kW/m at emplacement, subject to the thermal energy density constraint, decays with time to resemble the reference thermal line load used for performance assessment (SNL 2008, Figure 6.1-12).

The foregoing discussion of the waste package energy density calculation, and the postprocessing of the total system model output, describes the initial proof-of-concept. For repository operation, to demonstrate emplacement in conformance with thermal criteria, the WPLOAD V. 2.0 code (BSC 2007c) was developed and demonstrated. The estimated limiting waste stream was also used as input to the WPLOAD V. 2.0 code. This code simulates operations in the order in which waste packages are received and imposes throughput restrictions associated with the surface facilities. It also sends any commercial SNF waste package above the thermal emplacement limit (18 kW) to aging, until sufficiently cooled for emplacement. Waste packages are emplaced sequentially in each emplacement drift, one drift at a time. The average thermal power line limit (2.0 kW/m) is enforced for every possible seven-waste-package segment, incrementing the evaluated segment as each waste package is emplaced. Figure 1 represents the results from WPLOAD V. 2.0 simulation of the estimated limiting waste stream, demonstrating that the resulting emplacement sequence meets the maximum midpillar temperature of 96°C (running average thermal energy density), and also meets the constraints for maximum thermal line load and maximum thermal output for each waste package. A separate thermal analysis was performed using WPLOAD V. 2.0 to show that naval waste packages can be emplaced as part of the total waste package inventory.

SAR Figure 1.3.1-9 summarizes the approach for demonstrating that repository thermal loading conforms to thermal limits. The approach is implemented using the total system model, the WPLOAD V. 2.0 code (BSC 2007c), supporting finite element simulations, and the postclosure models that describe the anticipated responses of the geomechanical, hydrogeologic, and geochemical systems (SNL 2008, Section 6.4).

2. COMMITMENTS TO NRC

None.

3. DESCRIPTION OF PROPOSED LA CHANGE

None.

4. REFERENCES

BSC (Bechtel SAIC Company) 2007a. *Engineering Study: Total System Model Analysis for Repository Postclosure Thermal Envelope Study, Phase 1*. 000-00R-G000-00600-000-001. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20070905.0023.

BSC 2007b. *Engineering Study, Total System Model Analysis for Repository Postclosure Thermal Envelope Study, Phase 2*. 000-00R-G000-01000-000-000. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20071023.0006.

BSC 2007c. *Evaluation of Waste Stream Receipt Scenarios for Repository Loading*. 800-00C-WIS0-00500-000-00B. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20071220.0004.

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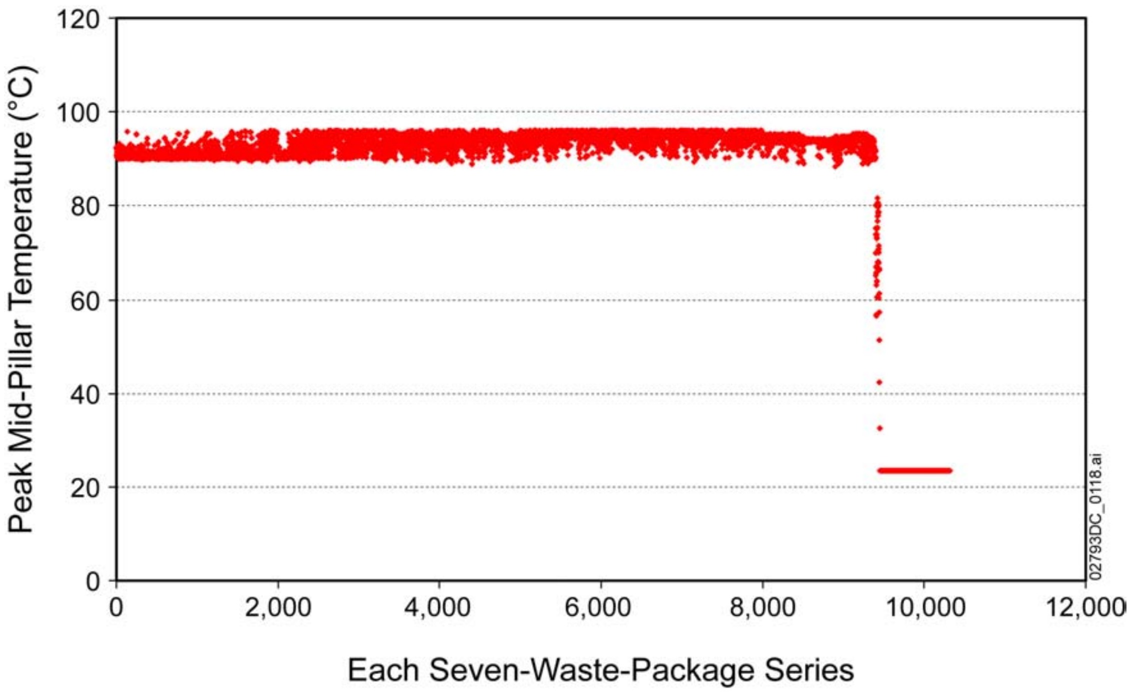

Figure 1. Peak Midpillar Temperature (°C) Over Each Seven-Waste-Package Segment for the Estimated Limiting Waste Stream.

NOTE: Data entries (dots) in the figure represent the calculated midpillar temperatures for the series of seven-waste-package segments, with the waste package segments being incremented one waste package at a time. The estimated limiting waste stream contains a total of 10,324 waste packages (BSC 2007c, Case 3b in Table 12).

The drop in midpillar temperatures towards the end of the series is due to the fact that the hotter, commercial spent nuclear fuel waste packages comprising the estimated limiting waste stream and a major portion of the cooler, noncommercial waste packages are emplaced in the earlier years, and the remaining cooler, noncommercial waste packages are emplaced in the later years of emplacement. Hence, the estimated limiting waste stream is conservative from a thermal loading perspective than what the actual emplacement mode would be (i.e., emplacing the cooler noncommercial waste packages with commercial spent nuclear fuel waste packages as the noncommercial waste is made available to the repository).

Source: BSC 2007c, Figure 7.